3|PRTS JC09 Rec'd PCT/PTO 10 JUN 2005 10/538605

SYSTEM AND METHOD FOR LIGHTING CONTROL NETWORK RECOVERY FROM MASTER FAILURE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is related to recovering the ballast control in a wireless lighting control network when the main controller (master) fails. More particularly, this invention is related to a wireless lighting control network system and method in which all lighting ballasts act as backups for a network master control unit. Most particularly, this invention is related to a system and method for a master-slave architecture for a wireless lighting control network that include all lighting ballasts as backup for a network master control unit such that there is no need for reconfiguration of the network or human intervention when a master fails or functioning of the master or slave ballasts is interrupted.

2. Description of Related Art

Traditional lighting has wall switches wired to the ballasts individually or in groups. If one of the switches fails, the ballasts that are controlled by other switches won't be affected. In wireless control, the on/off or light intensity is controlled by the signals transmitted from a remote table-top or handheld control unit via infra-red (IR) or radio frequency (RF) communication media.

There are basically two types of system configurations in wireless control. One is a distributed system that has several remote control units, each remote unit controlling a certain number of ballasts through the wireless links. The ballasts obtain the IDs of their designated controllers during the initialization of the system. Then, during normal operation the ballasts

"listen" and react to the lamp operational signals coming transmitted by these controllers. The systems described in U.S. Patent No. 5,848,054 to Mosebrook et al. and U.S. Patent No. 6,174,073 to Regan, fall into this category.

The other type of system is a master-slave oriented networked architecture, which is the focus of this invention. There is one central device, so called "master" or "network coordinator" that manages communication among the network nodes. The ballasts and the remote controls both act as the slaves in the network. All the information about the wireless links between the keys on the remote control and the ballasts is gathered in a table stored in the master during initial configuration of the system. During the normal operation, the signal transmitted by a remote control is routed to its destination ballast by the master based on the link information in the table. The physical form of the master can be the same as a slave device, i.e. the master can reside in the remote control or the ballast. It is preferable to put the master in the ballast as it is mains-powered and at a fixed location. Connecting to the mains allows the master to transmit beacon packets that contain the master status information as a way to keep the slaves in touch every once in a while. Being at a fixed location avoids problems a missing handheld remote control since all the network information is lost in such a case.

The master-slave networked system has the following advantages over the distributed system:

- If more than one remote-control is needed in a multi-zone office, a separate master is essential for network recovery if a remote control is lost.
- A master-slave architecture centralizes the control information for the local network and makes it easier to form the building-wide network.

In both wireless systems, there could be several reasons for a system failure:

- <u>Power Loss</u>: In normal operation, the ballasts should not be cut off from the mains

power for any reason, as they have to keep the RF communication alive all the time. Turning-off the lamps only puts the lamp-drivers in stand-by in digital ballasts, and it does not shut off the power supply to the circuits. Sometimes the controller that happens to be installed on a different mains power line from the ballasts experiences a power outage. Other times the controller could be running out of battery if battery powered.

- Circuit malfunction: This includes circuit failures in the master control unit (MCU) or RF transceiver, and the temporary RF signal blockage/shielding or interference such that the communications between the devices are blocked.
- Master Control Unit Failure: In a wireless network the master control unit represents a single point of failure. That is, once the master fails, all link information kept only by the master is lost. In a point-to-point network the network is no longer operable. This also occurs because the master routes all the packets and the master fails.

There are several ways to enhance the reliability. The wireless system taught by US Pat. No. 5,848,054 to Mosebrook et al., increases the reliability communications by adding repeaters between the source and destination devices. When the master and the ballasts suffer from intermittent communication in the direct path due to distance or RF interference, a repeater provides an additional communication path. However, this does not solve the problem of the master going completely dead.

Another system, taught by EP0525133 to Edwards et al., solves the master power outage problem by providing a battery as a back-up power source. When AC power is available, the battery is being charged. When the AC is cut off, the power supply automatically switches to the battery. Even though this idea teaches a battery backup for conventional hardwired lighting systems, it can be applied to the wireless system too. However, it can be costly to provide an additional power supply to every control device.

In a master-slave networked system, due to the important role of the master, it is critical to make sure that there is always a master working properly at all times. If the controller fails due to a power outage (dead battery) or malfunction, the problem arises of to how to regain controls of the ballasts. New replacements can be brought in, but the configuration, such as which key to control which ballasts, has to be set up again since there is no hardwiring in a wireless control system. Depending on how the wireless control network is built in the first place, sometimes this may mean starting the configuration from scratch all over again.

SUMMARY OF THE INVENTION

The present invention solves the problems associated with a single master, as discussed above, by providing multiple back-up masters in a master-slave orientated control network. The system and method of the present invention enhances system reliability without an extra device or costly circuitry. Each ballast in the network has the potential to be a master when needed. This means each device needs a little bit of extra memory to store the master program. In a digital ballast, the cost for additional memory is minimal.

The master malfunction is automatically detected by the slaves in the network. Once a master fails, a back-up master takes control of the network following a pre-established protocol or algorithm of a preferred embodiment. The network recovery takes place automatically and is transparent to the end user. There is no need to set up the network control configuration again.

The original master resides in one of the ballasts after the installation and configuration of the network, which includes the physical installation, registration of the ballasts with the network master (so called "enumeration"), and associating the ballasts with certain buttons on the remote control (so called "binding").

All the ballasts (slaves in the network) have the possibility and capability of becoming

the new master if needed. It is randomly decided, when necessary, which ballast is the next back-up master. There is no priority number assigned before hand.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a flowchart of the back-up master operation taking over control of the network.

FIG. 2 illustrates the failure of a network master control unit and several slaves of the same wireless lighting network.

FIG. 3 illustrates recovery of a network master control unit from a power outage.

DESCRIPTION OF PREFERRED EMBODIMENTS

The wireless lighting control network functions analogously to a wireless communication network. The lighting network itself is identified by a network ID, which is the essential information for communication among all the network nodes and there is a several layer communication protocol stack associated with every component of the wireless lighting network. After the network is established by the master and an enumeration of the lighting elements and pairing of enumerated lighting elements with keys are done, the master has all the pairing information stored in a pairing-link table in the protocol stack. Each pairing-link table entry specifies which ballast(s) reacts to which key and on which remote control. The master transfers this pairing-link table to all the slaves in the network. Every time the pairing-link table is changed, the master keeps all the slaves updated.

Master and slaves exchange status information at pre-determined intervals to make sure that the master is working properly. The master sends out beacon packets that contains status information at these certain intervals. The slaves receive the beacon packets and determine the state of the master. As illustrated in FIG. 1, at step 11 slaves also wake up a master that is in its sleep mode at intervals t_1. Each slave keeps in touch with the master with the same interval but at a different point of time (based on a randomly generated number).

Once a slave finds that the master is not working, at step 13 it waits a certain delay time t_2 before taking any action in case the master become operational again. Once the delay is timed out, at step 15 the first slave who discovers the master-failure will start to convert itself to the new master. While the first slave is waiting, the rest of the slaves can find out the master-failure too, but all of them have to wait for the same delay t_2 before reacting, so the first to discover the master outage becomes the new master.

The new master switches to the master status using the master code that has already been stored in its memory.

The new master establishes the network using the same network ID that the previous master used, providing this network ID is not used by any other networks in the vicinity. Then the application layer of the master does the following, as shown in FIG. 1.

1. Informs the lower layers in the new master to act as a master (sending beacons…) using the same network ID.
2. At step 15 informs the slaves that a new master is taking over the network and they should synchronize with the new master in terms of listening to the beacons and checking the master's status.
3. At step 16 updates the pairing-link table and transmits a copy of it to all the slaves.

The algorithm of the present invention can be implemented in combination with a wireless communication protocol, either proprietary or open standard to ensure a reliable RF

communication such as Zigbee™. Zigbee™ is a low cost, low power consumption, two-way, wireless communications standard aimed initially at automation, toys, & PC peripherals, and is a good candidate for implementing this system and method of the present invention for a recoverable RF wireless lighting control network that uses slaves as backup masters.

Normal Operation

The very first time the system is installed, the master and slaves all take on the physical format of a ballast. In a preferred embodiment, their roles are distinguished by certain mechanisms or algorithms. In a given single room, there must be a master and at least one slave. All the devices, including master and slaves, have nonvolatile memories (NVM) to store the enumeration status information, network ID information and pairing-link table information. When the devices are initially powered up, the master checks its NVM to see if it has been in any network as a master before. If not, it establishes its network using a randomly generated network ID. The slaves check their NVMs to see if they have been in any network as a slave before, if not, they try to enumerate to a master available in their RF vicinity. Once they are connected to a master, the lamp flashes to provide feedback to the user and the user presses a button on the remote control to confirm that it should be included in the network. The remote control is also a slave to this network and has to be connected to the master before the ballasts.

Reasons for Master Failure

There are two major reasons for the master to fail:

1. Power Loss: During normal operation, both master and slave must not be cut off from the main power supply for any reason, as they have to keep the RF communication alive all the time. Turning off the lamps only puts the lamp drivers in stand-by, and it does not shut off the power supply to the circuits. When the ballasts are initially powered up from the main power supply, if a ballast is supposed to be a master, it starts to establish its network. If it is supposed to

be a slave, it starts to request joining a network. The ballasts store their IDs and network connection information (such as the pairing-link table, the flag indicating if it has been enumerated before, etc.) in the non-volatile memory so that the network connection can be recovered after a temporary power interruption. If the power of the whole system is consistently interrupted, then the ballasts maintain their previous roles after the power comes back. In this case, the power-up reset does not trigger the enumeration request in the ballast if it was already in a network previously. This scenario is not considered a master failure since the whole network recovers to its previous state before the power interruption without further procedures being invoked.

However, sometimes the master could be installed on a different main power line from the slaves. When its power is experiencing an outage and the one for the slaves is not, a back-up master is needed to keep the rest of the slaves under control.

2. <u>Circuit malfunction</u>: This includes failures in the MCU or transceiver and temporary RF signal blockage/shielding around the master, etc. In this case, a back-up master is also necessary to recover the operation of all the slaves.

FIG. 2 illustrates the master failure situation. If a circuit malfunction occurs and the network master control unit 22 is not functional, a new master control unit 28 takes over control of the existing lighting network by following the algorithm illustrated in FIG. 1. By way of example only, several slaves and a network master control unit 22 are shown in a non-working circuit in FIG. 2. The new network master control unit 28 takes control of the exiting lighting network 20, updates its pairing-link table to reflect these non-working units and transmits the updates to all the working slaves in the network.

<u>Disabled Master Coming Back</u>

In the case that the previous master recovers from its temporary RF blockage or power outage, it tries to join the same network again, but not as a master, instead, as a slave since there a

new master has already taken over control of the network. The following describes the two different situations where the previous master recovers from a temporary power outage and RF blockage. If the previous master failure is due to circuit malfunction, it cannot recover anyway.

1. <u>Coming back from temporary power outage</u>

Referring now to FIG.3, when the previous master regains power 31, it goes through the power-up reset and then checks the contents of its NVM. When its NVM indicates that it was previously the master of a network 34, it tries to recover its role as master in the same network by attempting to establish its network using the same network ID 34. It starts the search at this particular network identifier, and then listens for a beacon packet to see if anyone else is already using this network ID 35. As soon as it finds out that another device has already taken its place as the master in this particular network (using the previous network ID), it withdraws itself from attempting to become the master again, and it enumerates to the network as a slave 36. Since the network ID is still the same, it does not require any user intervention during the enumeration.

As can be seen in FIG. 3, some of the slaves might have been out of power, as well, if they were on the same power line as the previous master. When they regain power, they go through power-up reset and then check the contents of their NVMs. As their NVMs indicate that they were was previously slaves of a network, they try to recover this role as a the slave 36, in the same network by attempting to enumerate using the previous network ID. The new master is able to accept them without user intervention since the new master has the information that the slave has been in this network before the power was out.

2. <u>Coming back from temporary RF communication blockage</u>

When the previous master failure is due to the temporary RF communication blockage, the protocol stack is able to report this problem to the application layer. The application layer then goes back to the beginning of the routine, which is power-up reset. Then it keeps trying to re-establish its network using the same network ID 38. If, by the time the RF channel is clear for

communication for this device, the new master has already taken over the network, the old master withdraws from trying to become the master, but tries to become a slave, which is the same as the situation in coming back from temporary power outage and is discussed above and illustrated in FIG. 3.. If by the time the old master regains RF accessibility, \the new master has not yet taken control of the network, the old master recovers control over the same network with the same ID and this is illustrated in FIG. 3.

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will be apparent to those skilled in the art. The present invention, therefore, should be limited not by the specific disclosure herein, but only by the appended claims.